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Introductory Chapter: Turbulence and Related Phenomena

Régis Barillé

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1. Introduction

This book presents some of the last results concerning the atmospheric turbulence and all its effect on the propagation of light beam. This domain of research covers some related applications to optical communications and the understanding of new optical effects due to atmospheric conditions.

The process of optical beam propagation through random media has been studied for many years and has followed the development of the laser technology. The term random medium or turbulent medium means that the index of refraction of the medium exhibits random spatial variations with dimensions larger than the optical wavelength of the propagating optical beam. Fluctuations in the refractive index in air, i.e., air density, are caused mainly by temperature variations affecting the wave front of a light beam. Atmospheric refractions can cause spatial and temporal (intensity) variations in propagating beams. The fluctuations in the index of refraction of the earth's atmosphere result in many optical effects well-known to astronomers. Some of these effects are twinkling (variation of image brightness), quivering (displacement of image from normal position), smearing of the diffraction image, wandering (continuous movement of a star image about a mean point), wandering (slow oscillatory motions of the image for a period of approximately 1 minute and angular excursions of a few seconds of arc), pulsation (fairly rapid change of size of the image), image distortion, and boiling (time-varying nonuniform illumination in a larger spot image) [1, 2].

The first studies concerning the propagation of unlimited plane waves and spherical waves through random media led to the classical books published in the early 1960s by Tatarskii, *Wave Propagation in a Turbulent Medium*, and LA Chernov, *Wave Propagation in a Random Medium*. VI Tatarskii predicted based on his theory considering weak fluctuations that the correlation width of the irradiance fluctuations is on the order of the first Fresnel zone L/k where L is the distance

to the source and k is the wave number. Their results concerning optical scintillation were only limited to weak fluctuations. However, in the case of high turbulence, saturation effects of optical waves occur and were first experimentally demonstrated later by ME Gracheva and AS Gurvich in 1965. The publication of this work stimulated a lot of theoretical and experimental studies related to irradiance fluctuations under conditions of strong turbulence. So, the base for the development of studies concerning turbulence effects on laser beam in atmospheric turbulence was set down. Later in the aim to better improvements of the theoretical bases of the saturation phenomenon, several qualitative models describing the underlying physics associated with amplitude or irradiance fluctuations were developed in the mid-1970s. A generalization of the Tatarskii's physical optics model was published where the loss of spatial coherence of the wave as it propagates into the strong fluctuation regime was included.

Until now, there are no easy solutions to deal the problem of irradiance fluctuations that applies to all conditions of optical turbulence for the propagation of electromagnetic waves. This problem recently gains importance since free space optical communications (FSO) is now common for point-to-point communications not only between fixed locations on land but also for communication between moving platforms like vehicles on land, on the surface of the sea, in air, and in space [3]. Free space communications imply that it is not practical or impossible to use optical fiber technology to connect the points that need to communicate or exchange data. Since the beginning of the twenty-first century, there is a growing interest in increasing the capacity of free space telecommunication systems to eventually the pending bandwidth limitation. The current development of new protocols in free-space optical communication requires the knowledge of light beam propagation in a turbulent medium and the possibility to change the laser beam parameters (beam shape, coherence, etc.). FSO is a technology that uses the visible and infrared light propagating through the atmospheric medium to transmit information. However, the constitution of the atmosphere involves turbulence, particularly aerosols (fog, smoke, and dust) have similar particle size distributions compared with optical wavelengths in FSO. In another domain of activities atmospheric turbulence induces spatial and temporal changes during the light propagation and in transmitted signals acquired by the receptors. In turn, these effects can significantly degrade (blur, shimmer, and distort) optical data. This can also potentially result in scattering and absorption of visible and IR optical beams. Even in clear outdoor conditions, wireless optical links experience fluctuations in both the intensity and the phase of an optical wave propagation.

These conditions lead to degradation of the FSO link performances and its availability for a large development in particular in an urban environment where the conditions of propagation are not clearly understood. Moreover, in some cases, the atmospheric parameters can impact the beam propagation and give insights of the turbulence phenomena involved. For all these reasons, it is important continuing to develop studies on light beam in atmospheric turbulence.

Author details

Régis Barillé

Address all correspondence to: regis.barille@univ-angers.fr

MOLTECH-Anjou, University of Angers/UMR CNRS 6200, Angers, France

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